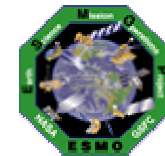




International EESS Wideband Workshop

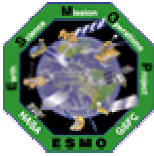
March 24-27, 2003

Orlando, Florida



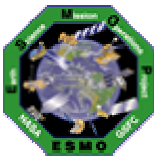
Earth Science Morning and Afternoon Constellations

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TOPICS

- Constellation/Formation Flying
- Morning Constellation (Morning Train)
 - Description
 - Mission Characteristics
 - Lessons Learned
- Afternoon Constellation (A-Train)
 - Description
 - Mission Characteristics
- RF Analysis
- Use of Direct Broadcast Data
- Summary



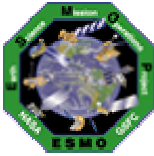
NASA Earth Science Missions

NASA Earth Science Enterprise Mission:

The overall mission of NASA's ESE is to develop an understanding of the total earth system and the effects of natural and human-induced changes on the global environment.



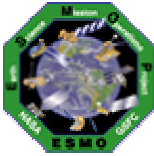
Constellation/Formation Flying



- Earth Science morning and afternoon constellations are in repeating, sun-synchronous orbits within a few minutes of each other that enable coincident imaging or coincident observations.
- Constellation Flying--a group of satellites flying in orbits that enable coincident imaging or coincident observations
- Formation Flying
 - In the strict sense, according to Flight Dynamics, refers to tight coupling between 2 or more satellites.
 - One satellite is burdened with doing maneuvers for the sole purpose of maintaining a position with respect to another satellite (kind of like a pseudo-rendezvous).
 - For example, in the Afternoon (A) Train, CloudSat, CALIPSO, and PARASOL are formation flying with each other. CloudSat is the burdened satellite and will maneuver to keep in formation with CALIPSO.



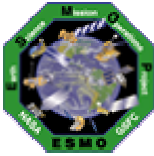
Constellation/Formation Flying Objectives



The constellation can be thought of as a single “virtual” platform which:

- increases the quality of the science
- increases the synergy between observing instruments,
- provides new observing capabilities,
- explores the utility of coordinated synoptic observations proposed for future missions,
- compares new instrument capabilities, and
- allows for coordinated validation and calibration efforts.

“ The sum is greater than the parts...”

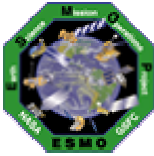


Two Earth Science Constellations

- Morning set, led by Landsat-7
- Afternoon set, led by Aqua (EOS PM-1)



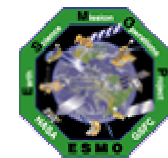
Morning Constellation Description



- The Morning Constellation, also known as the Morning Train, consists of 4 satellites:
 - Landsat-7, launched in April, 1999, leads the train
 - Terra, launched in December 1999, is the “caboose”
 - EO-1 and SAC-C joined the constellation on November 21, 2000
- As a constellation, the satellites fly within minutes of each other between 10:00 a.m. Mean Local Time (MLT) and 10:30 a.m. MLT

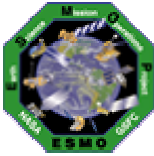


Morning Constellation





Morning Constellation Mission Description

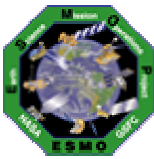


- Landsat-7:
 - follow-on mission to continue the global data record collected by previous Landsat missions;
 - the ETM+ instrument is an eight-band multi-spectral scanning radiometer capable of providing high resolution image of the Earth's surface
- Terra (formerly AM):
 - first of the large Earth Observing System (EOS) spacecraft; started long term monitoring of global climate change and environmental change
 - First global and seasonal measurements of the Earth's system, including such critical functions as biological productivity of the land and oceans, snow and ice, surface temperature, clouds, water vapor, and land cover



Morning Constellation

Mission Description, continued

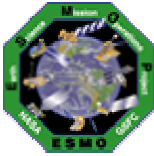


- Terra (formerly AM), continued:
 - Carries five instruments:
 - Moderate Resolution Imaging Spectroradiometer (MODIS)-- with a wide field of view (2300 km), provides images of daylight-reflected solar radiation and day/night emissions over the entire globe
 - Clouds and the Earth's Radiant Energy System (CERES)--two broadband scanning radiometers measure reflected sunlight, Earth-emitted thermal radiation, and total radiation
 - Measurements of Pollution in the Troposphere--this is a scanning radiometer designed to measure from space for the first time carbon monoxide and methane concentration in the lower atmosphere.
 - Multi-Angle Imaging Spectroradiometer--with nine cameras, the Earth's surface is successively image, each in 4 wavelengths.
 - Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)--provides the highest resolution images of the Terra instruments (15-90 m). Images can be obtained in visible, near-infrared, short-wave infrared, and thermal infrared wavelengths



Morning Constellation

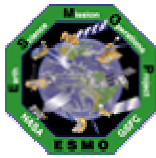
Mission Description, continued



- EO-1: flying in formation 1 minute behind Landsat 7 in the same ground track and maintaining the separation within 2 seconds; observes the same ground location (scene) through the same atmospheric region so that paired scene comparisons between the two satellites can be made.
 - All three of the EO-1 land imaging instruments (Advanced Land Imager, Hyperion, and Atmospheric Corrector) view all or subsegments of the Landsat 7 swath.
 - part of NASA's New Millennium Program, EO-1 focuses on the development and test of advanced technology land imaging instruments
- SAC-C: an international cooperative mission between NASA and the Argentine Commission on Space Activities (Comision Nacional de Actividades Espaciales (CONAE)) to study the structure and dynamics of the Earth's atmosphere, ionosphere, and geomagnetic field.
 - Provides multi-spectral images of the Earth in order to monitor the condition and dynamics of the terrestrial and marine biosphere and environment



Morning Constellation Characteristics

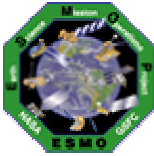


Spacecraft	Land sat-7 (Le ad)	EO-1	SAGC	TERRA
Launch	04 / 1999	11 / 2000	11 / 2000	12 / 1999
Current MLT (descending node)	10:00	10:01	10:245	10:30
X-Band Freq. GHz	8.083 8.213 8.343	8.225	8.386	8.213
Science Downlink	X-Band	X-Band	X-Band	TDRSS Ku-Band (X-Band BU)
Data Rate	150 Mbps channel	105 Mbps	3.774 Mbps	150 Mbps 13.125 Mbps (DB)
Ground Station Requirement	AGS, SGS, EDC	SGS (Primary) AGS, EDC, WPS (BU)	ETC	SN-Prime AGS, SGS (BU)
S-Band Freq. MHz	2287.5	2215.5	2255.5 2244.0	2287.5
Data Rate	1.216 & 4.864 Kbps RT 256 Kbps PB	2 & 32 Kbps RT 1 Mbps PB 2 Mbps (BU)	1 Kbps RT 1.886 Mbps PB	16 Kbps RT 256 Kbps PB
Ground Station Requirement	EDC RT & PB SGS, AGS – RT & PB	SGS RT & PB AGS, AKS, WPS (BU)	AGS, PF1, WPS, MGS, ETC	EPGN Backup
DB	No	No	No	Yes



Afternoon Constellation

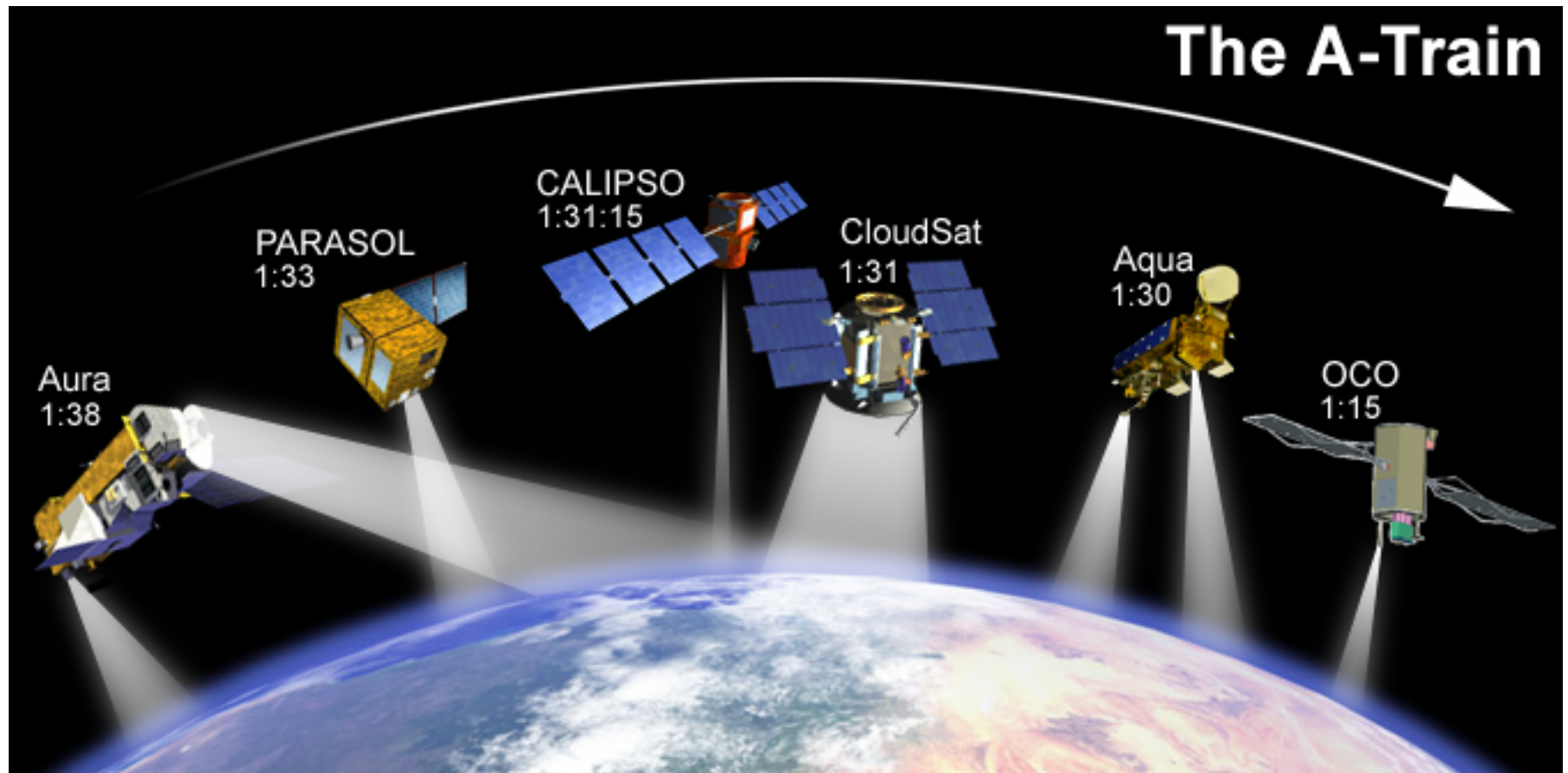
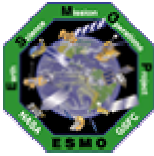
Description



- The Afternoon Constellation, also known as the A-Train, consists of 6 satellites: EOS Aqua, CloudSat, CALIPSO, PARASOL, EOS Aura, and OCO.
- As a constellation, the satellites fly within minutes of each other between 1:15 Mean Local Time (MLT) and 2:00 p.m. MLT.
- Aqua, launched on May 4, 2002, leads the train.
- Aura, formerly known as EOS Chem, is scheduled for launch in January 2004. Aura is the “caboose”.
- CloudSat and CALIPSO are co-manifested for a launch in October 2004.
- PARASOL, a French/CNES satellite, is scheduled for launch in Oct 2004.
- OCO is scheduled for a 2007 launch and will end up as the lead satellite in that timeframe.



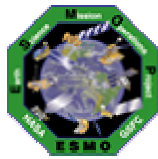
The Afternoon Constellation





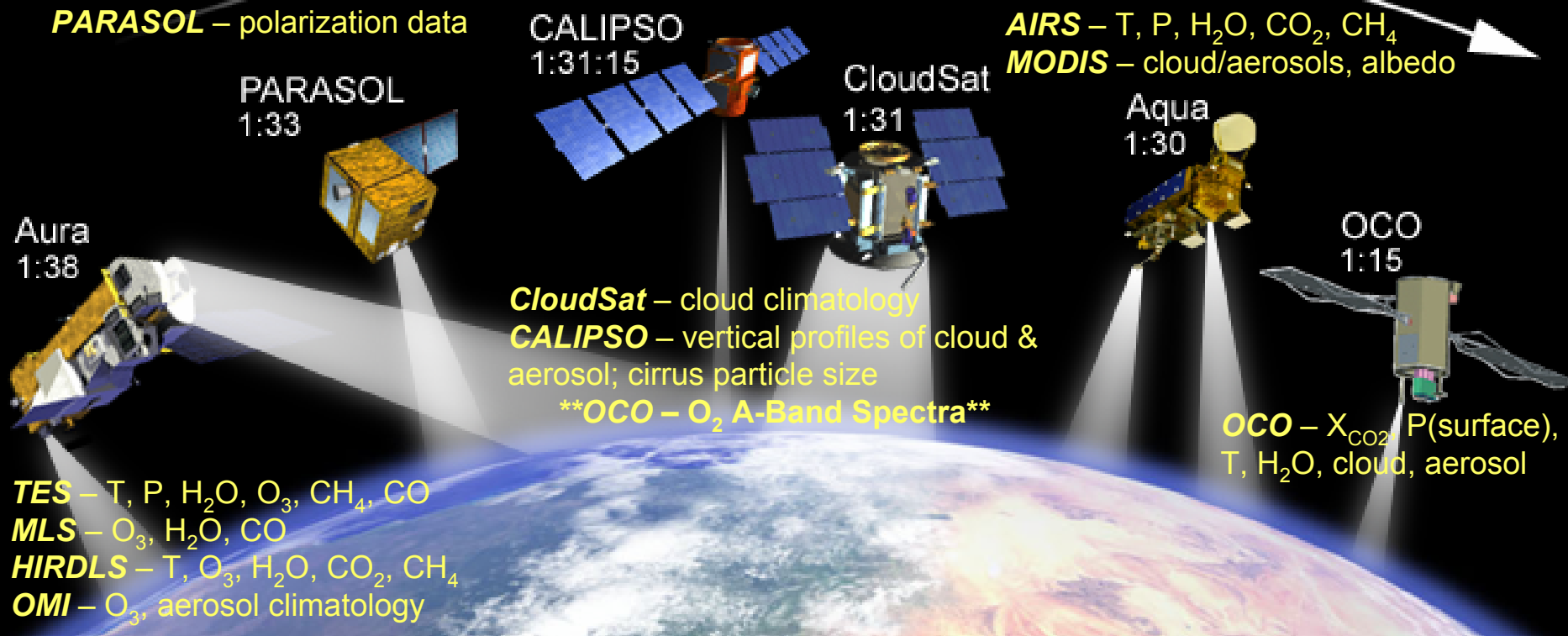
The Afternoon Constellation

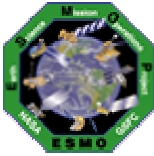
(OCO Perspective, presented at
A-Train Working Group Meeting, March 17-18, 2003)



Coordinated Calibration/Validation Activities

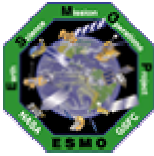
The A-Train





Afternoon Constellation Mission Description

- Aqua: As the second EOS spacecraft, Aqua's instruments are designed to understand the Earth's water or hydrological cycle and collect data on the geographical distribution of clouds and aerosols, atmospheric temperature, moisture content, and the radiation balance at the top of the atmosphere.
- Aura: will study the Earth's ozone, air quality and climate. It is designed exclusively to conduct research on the composition, chemistry and dynamics of the Earth's upper and lower atmosphere employing multiple instruments on a single satellite.
- CALIPSO: will provide vertical, curtain-like images of the atmosphere on a global scale using a lidar (light detection and ranging) using short pulses of laser light to probe the atmosphere. This will help scientists to determine precisely the altitudes of clouds and aerosol layers and the extent of layer overlap, to identify the composition of clouds and to estimate the abundance and sizes of aerosols.



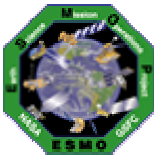
Afternoon Constellation

Mission Description, continued

- CloudSat: a sister satellite to CALIPSO, will fly in tight formation with CALIPSO. This mission will use a radar to provide vertical profiles of thick clouds that lidar cannot penetrate.
- PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar) satellite, being developed by CNES, will provide unique information on aerosols and clouds using a multi-channel, wide field-of-view, polarization-sensitive camera.



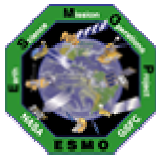
Summary of A-Train Missions



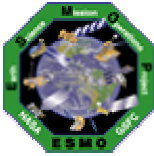
Spacecraft	Position in A-Train Formation Requirements	Instruments	Launch Date	Responsible Organization
Aqua	Lead spacecraft until the launch of OCO	AIRS/AMSUA/ HSB AMSR-E CERES MODIS	May 2002	NASA/GSFC
CloudSat	Lags Aqua by between 15 seconds to 2 minutes. Must maintain extremely precise positioning relative to both Aqua and CALIPSO.	CPR	October 2004	NASA/GSFC NASA/JPL
CALIPSO	Lags CloudSat by no more than 15 seconds. Must maintain position relative to Aqua < 2 min.	CALIOP IIR WFC	October 2004	NASA/GSFC NASA/LARC CNES
PARASOL	Lags CALIPSO by ~ 1min	POLDER	October 2004	CNES
Aura	Lags Aqua by ~15 min but crosses equator 8 min behind Aqua on a different orbital track	HIRDLS MLS OMI TES	January 2004	NASA/GSFC
OCO	Will precede Aqua by 5 minutes when it is launched.	Three grating spectrometers	2007	NASA/GSFC NASA/JPL



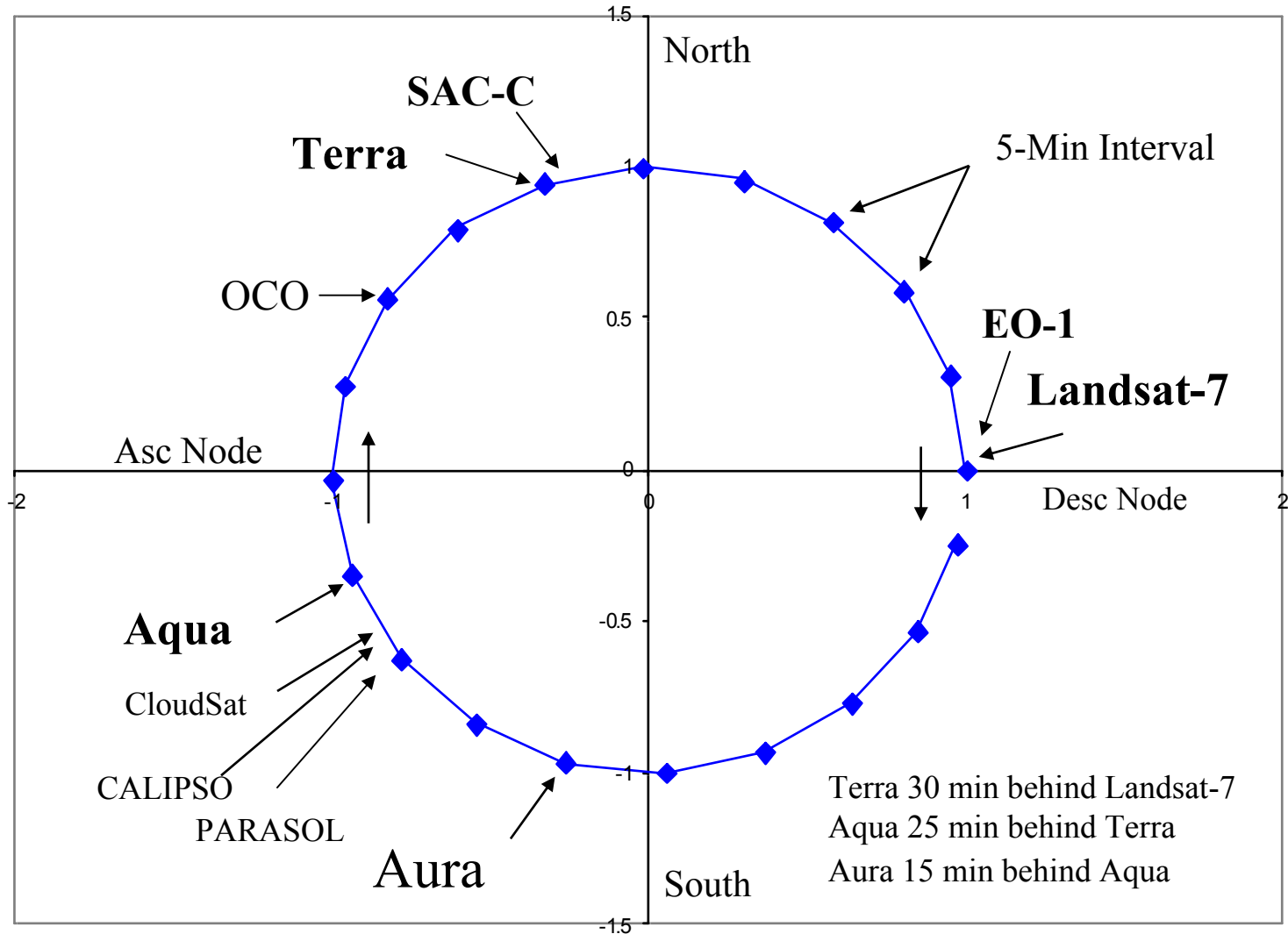
Afternoon Constellation Characteristics

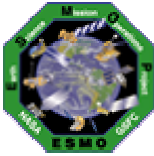


Spacecraft	Aqua (Lead)	Aura	CALIPSO	CloudSat	OCO	PARASOL
Launch	05/04/02	01/29/04	10/22/04	10/22/04	Early 2007	10/04
MLT (ascending node)	13:32	13:30-14:00 (Aqua+8 min)	13:31:26	13:32:32	13:15 – 13:30	13:30
X-Band Freq. GHz	8.160	8.160	8.33	n/a	8.19	8.0
Science Downlink	X-Band	X-Band	X-Band	S-Band	X-Band	X-Band
Data Rate	15 Mbps DB 150 Mbps DP	15 Mbps DB 150 Mbps DP	80 Mbps	5 Mbps	150 Mbps	16.8 Mbps
Gnd. Station Requirement	AGS/PF1 SGS/SKS WGS	AGS/PF1 SGS/SKS WGS	USN@ Alaska& Haw	AFSCN SAFB OAS	USN Alaska Sweden (BU)	CNES TTTET PDDS
S-Band Freq. MHz	2287.5	2287.5	2268.5	2200	2000	TC: 2033.2 TM: 2208
Data Rate	2 kbps 16.384 kbps 524.288 kbps	2 kbps 16.384 kbps 524.288 kbps	20kbpsTC 400 kbps 25 kbps emergency	TBD	2 mbps TM 2 kbps TC	20kbpsTC 400 kbps 25 kbps emergency
Gnd. Station Requirement	AGS/PF1 SGS/SKS WGS	AGS/PF1 SGS/SKS WGS	CNES TTTET PDDS	AFSCN SAFB OAS	USN Alaska Sweden (BU)	CNES TTTET PDDS
DB	Yes	Yes	No	No	No	No



Relative Positions of Satellites in the Morning and Afternoon Constellations (From Ground Station Perspective)





A-TRAIN

S-Band RF COMPATIBILITY ANALYSIS*

- CNES has not identified interfering issues between NASA and CNES missions within the A-Train (even with a worse case approach).

TC :

1800 MHz	1820 MHz	2000 MHz	2020 MHz	2040 MHz	2060 MHz	2080 MHz	2100 MHz
	CLOUDSAT 400 kHz	AQUA 150 kHz	PARASOL 150 kHz				CALIPSO 150 kHz

- Note: does not include OCO

TM :

2202 MHz	2204 MHz	2206 MHz	2208 MHz	2210 MHz	2212 MHz	2214 MHz	2216 MHz	2218 MHz
			PARASOL 1.2 MHz					CLOUDSAT (W) 4 MHz

2256 MHz	2258 MHz	2260 MHz	2262 MHz	2264 MHz	2266 MHz	2268 MHz	2270 MHz	2272 MHz
			CLOUDSAT (N) 1 MHz			CALIPSO 2 MHz		

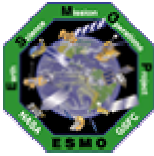
2282 MHz	2284 MHz	2286 MHz	2288 MHz	2290 MHz	2292 MHz	2294 MHz	2296 MHz	2298 MHz
			AQUA 2 MHz					

**-from CNES PARASOL presentation,
A-Train MOWG, 3/17/03*



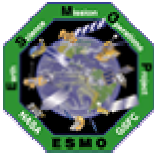
USE OF DIRECT BROADCAST DATA*

Sentinel Hotspots



- Fire identification system developed by Australian scientists.
- Provides big-picture of fires across the country
 - Helps fire emergency agencies allocate resources to areas needed.
- Makes use of MODIS data from Terra and Aqua satellites.
 - Uses MODIS direct broadcast signal.
 - Three ground stations currently in use, a fourth is planned.
- Dedicated computer at one ground station analyzes data.
 - Up to four down-links in a 24-hour period
 - Five minutes of down-linked data creates a 400 mb file.
 - Scans for unusually high amounts of thermal and short wave infrared radiation detected by MODIS.
 - Indicate possible fires.
 - Computer creates a small file of hot spot indications
 - Sent out to interested parties/agencies in less than an hour of receipt

**from <http://earthobservatory.nasa.gov/Study/Sentinel/sentinel.html>*



Sentinel Hotspots (cont.)

- Similar to U.S. MODIS Rapid Response Project
 - Developed at GSFC with University of MD, NOAA and U.S. Forest Service.
 - Provides near realtime fire detection from MODIS to National Interagency Fire Center in Salt Lake City, UT
- Sentinel Problems With MODIS X-Band Resolved
 - Dropouts in MODIS X-band data caused problems for Sentinel
 - Caused by MODIS X-Band scheduled blackouts in certain areas of world
 - Done to reduce possible RF interference with Deep Space Network stations
 - Canberra was one such station.
 - Deep Space Network personnel provided waiver to stop blackouts in most cases.

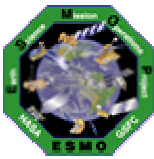
Sentinel Hotspots (cont.)



Burn scars appear as dark reddish smudges against the brown and green grasslands. Faint gray smoke rises above some actively burning fires. This true-color image was acquired on October 16, 2002. (Image courtesy MODIS Land Rapid Response Team at NASA GSFC)



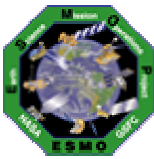
Sentinel Hotspots (cont.)



At sunset, smoke from bushfires approaching the Canberra Deep Space Network in Tidbinbilla billows over a ridgeline near Mount Pleasant. Image courtesy of Fred Pilcher.



Sentinel Hotspots (cont.)



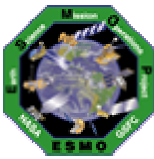
Satellite data from the Moderate Resolution Imaging Spectroradiometer showed both immense plumes of smoke and the location of active fires (red dots). This image was acquired February 4, 2003. (Image courtesy MODIS Land Rapid Response Team at NASA GSFC)



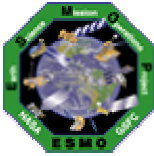
At the Sentinel Hotspots Website, anyone can create maps of active fires detected by MODIS. The image shows the fires detected around Canberra between January 14 and 17, 2003, along with latitude and longitude lines, the boundary of the Australian Capital Territory (larger gray outline), and the urban limits of the city of Canberra (small gray outline filled with cross-hatching).



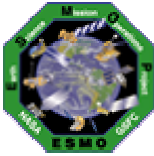
SUMMARY



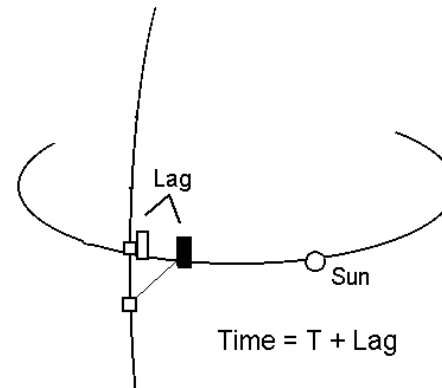
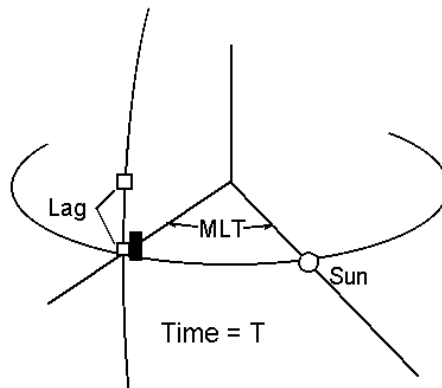
- The entire Morning Constellation has been in orbit since Nov 21, 2000.
 - Operations are continuing; images have produced excellent science
 - After initial difficulties, ground system resources have performed well; Terra supported primarily by Space Network
 - Learned lessons being applied to the Afternoon Constellation
- Afternoon Constellation: Lead Satellite, Aqua, in orbit since May 4, 2002
 - Aqua is producing excellent science
 - Aura, CALIPSO, CloudSat, and PARASOL are scheduled to launch in 2004; OCO is in the early formulation phase (2007 launch)
 - Coordination among missions in progress--Afternoon Constellation Working Group held March 17-18, 2003; Processes, guidelines, and tools for coordination are being developed
 - Ground system resources for EOS are coping with Aqua; loading analysis updates will be periodically updated
 - RF analysis needs to be revisited to include OCO



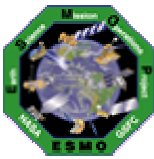
BACK-UP CHARTS



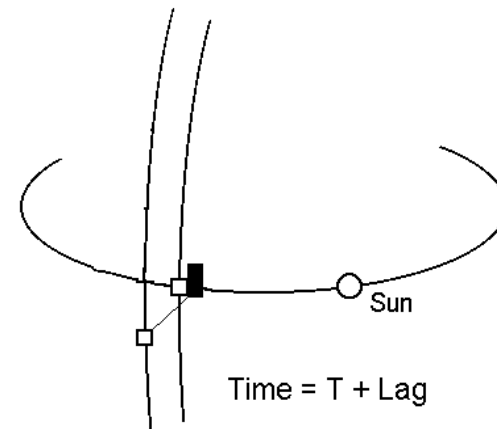
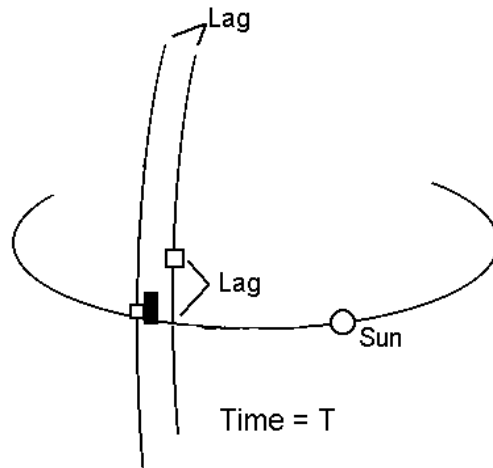
Two Spacecraft, Same Orbit Trajectory



These spacecraft view different scenes on the surface of the earth due to the Earth's rotation under their orbit plane.

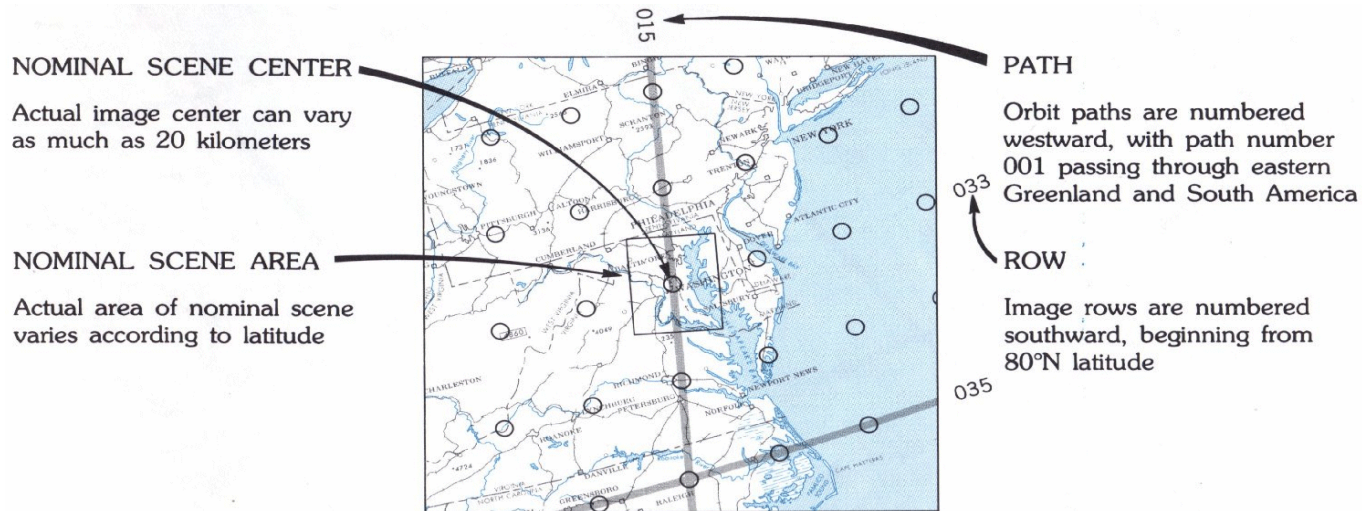


Two Spacecraft, Same Ground Trajectory



The orbit planes are offset so that each spacecraft passes over the same point on the ground.

The Earth Reference System Being Used.



This is the World Reference System-2 used by Landsats-4, -5, and -7 (courtesy of USGS, see <http://landsat7.usgs.gov>).